Open Sea Operating Experience to Reduce Wave Energy Costs

Technical Note

Mutriku pressure data winter 2016-2017

Lead Beneficiary	TECNALIA Research and Innovation
Delivery date	2017-07-12
Dissemination level	Public
Classification	Unrestricted
Version	1.0
Keywords	Pressure sensor, Wave Resource

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654444

Disclaimer

This Deliverable reflects only the author's views and the Agency is not responsible for any use that may be made of the information contained therein.

Document Information

Grant Agreement Number	654444
Project Acronym	OPERA
Work Package	WP 5
Task(s)	T5.3
Title	Mutriku pressure data winter 2016-2017
Author(s)	Iñaki Txarterina, Joannès Berque (TECNALIA)
File Name	OPERA_Deliverable Template_v0.docx

Change Record

Revision	Date	Description	Reviewer
1.0	12-07-2017	Winter 2016-2017 data	Coordinator

EXECUTIVE SUMMARY

This Technical Note describes the data collected by the RBR pressure sensor deployed in front of the Mutriku wave power plant, data processing to provide time series of sea-state variables, and quality checks.

In summary, the commonly used sea-state variables are obtained and compare favourably with measurements from an established buoy in the vicinity. The hourly time series is provided to the OPERA consortium and will be publicly available shortly.

A couple of issues should be mentioned here:

1. The energy mean period is not reliable when significant wave height is below 30 cm. As this is a rare occurrence of little interest to wave energy applications, this is not corrected but should be kept in mind by the user of the data
2. There is a (low probability) possibility that instrument sensitivity has decreased during deployment. This cannot be checked against reference at the moment but should be easy to correct in subsequent deployment as several pressure sensors will be deployed nearby

In the coming weeks the full, 2 Hz data, inclusive of correction for propagation time from sensor to wave power plant will be made available to the OPERA consortium.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. DESCRIPTION OF THE ORIGINAL PRESSURE DATA

To reach the final data, some calculations and transformation of the information has been done. This data was taken from a pressure captor, specifically RBR Virtuoso, located in Mutriku (coordinates: 43º18'52"N, 2º22'34"). The device is located roughly in 8 metres depth and it takes data in 2 Hz frequency, that means that the pressure captor takes information of the waves 2 times per second. The captor gives information about date, pressure (dbar), sea pressure (dbar), and depth (m), and it has been taking data from 2016-11-16 to 2017-02-03.

The table below shows small sample of it:

TABLE 1 SMALL SAMPLE OF THE ORIGINAL DATA

Date	Time	Pressure (dbar)	Sea Pressure (dbar)	Depth (m)
01/01/2017	00:00:00.000	19.0810930	8.9485920	8.8936039
01/01/2017	00:00:00.500	19.0276466	8.8951456	8.8404860
01/01/2017	00:00:01.000	18.9656692	8.8331682	8.7788893
01/01/2017	00:00:01.500	18.9094713	8.7769703	8.7230368
01/01/2017	00:00:02.000	18.8615576	8.7290566	8.6754175
01/01/2017	00:00:02.500	18.8279561	8.6954551	8.6420225
01/01/2017	00:00:03.000	18.8001664	8.6676654	8.6144035
01/01/2017	00:00:03.500	18.7850502	8.6525492	8.5993802
01/01/2017	00:00:04.000	18.7702434	8.6377424	8.5846644
01/01/2017	00:00:04.500	18.7562404	8.6237394	8.5707474
01/01/2017	00:00:05.000	18.7405061	8.6080051	8.5551099
01/01/2017	00:00:05.500	18.7241219	8.5916209	8.5388263
01/01/2017	00:00:06.000	18.7056065	8.5731055	8.5204247

The data was divided by SciLab, free and open source software for numerical computation, in files of hour-long records to ease the analysis and further calculations to reach the final objectives. In addition, these hourly data were plotted and analysed to see pressure variation during the hour, see the difference between high tide and low tide through the day.

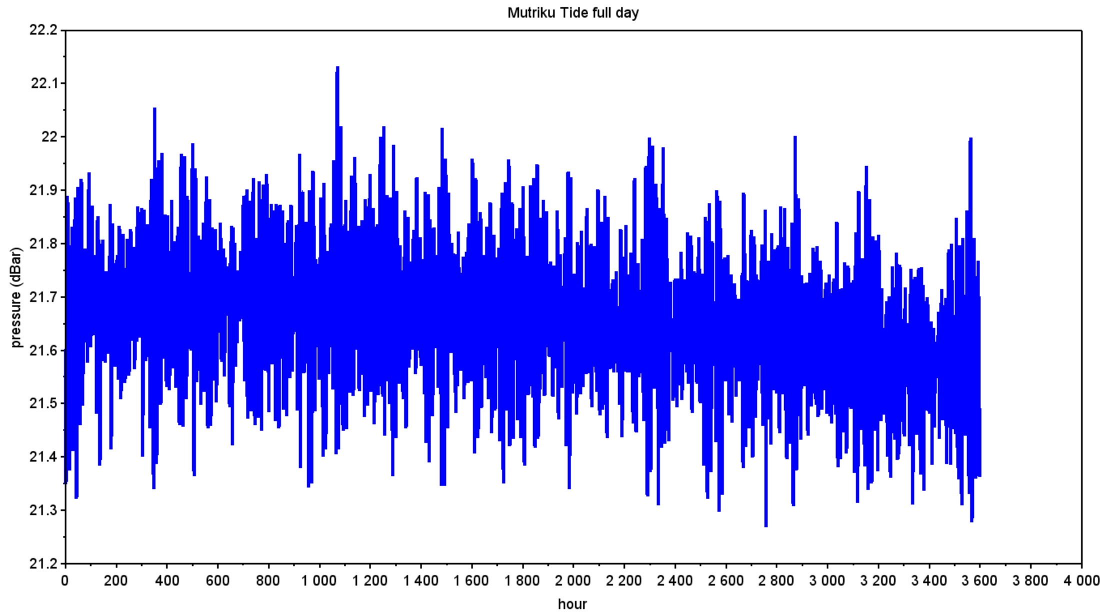

FIGURE 1 ONE HOUR PRESSURE DATA PLOT [1]

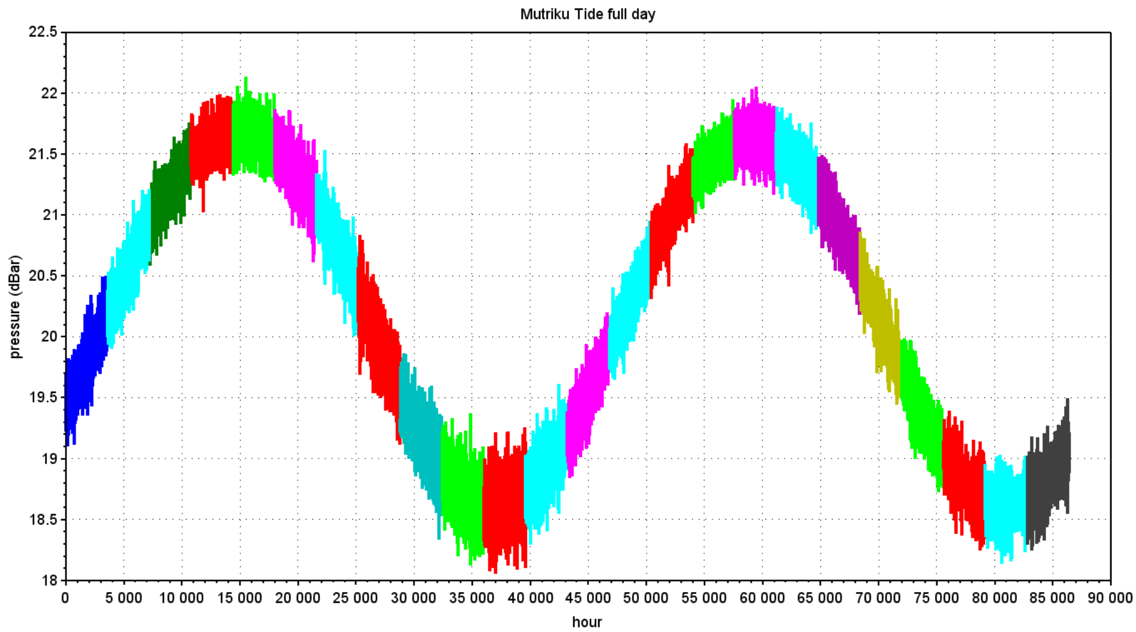

FIGURE 2 FULL DAY PRESSURE DATA PLOT SEPARATING HOURS WITH COLOURS [1]

2. 10-MINUTE MOVING AVERAGE

The moving average, also called running average, in statistics is used to analyse data points doing the average of a subsets of the full data set to form series of average data point.

In this case the moving average was made with ten-minute data centred on each data point (i.e. 5 minutes before and 5 minutes after) in order to remove the tidal and atmospheric variation signal and remain with wave height data. With this system and Scilab programme it is possible to plot horizontal data graph making easier the appreciation of the information.

The figures below show three-hour data plot, showing first pressure data with tidal variation and the line created by the Moving Average method, which is the line that links all ten-minute subset average points. And, showing after, the wave heights in these three hours without tide signal. [2]

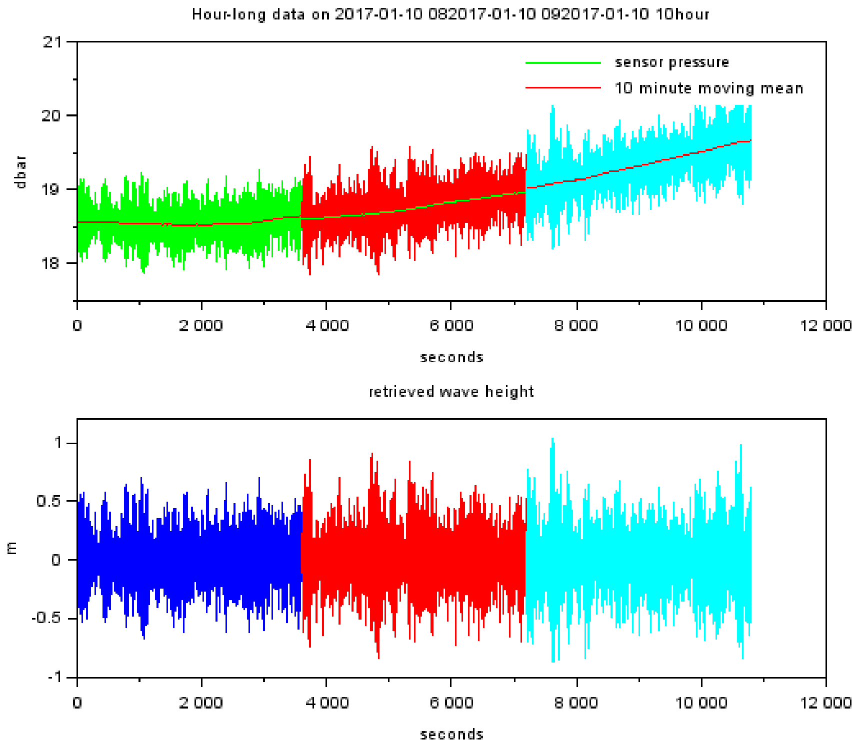

FIGURE 3 MOVING AVERAGE AND HEIGTHT CALCULATION WHEN TIDE IS GOING UP [1]

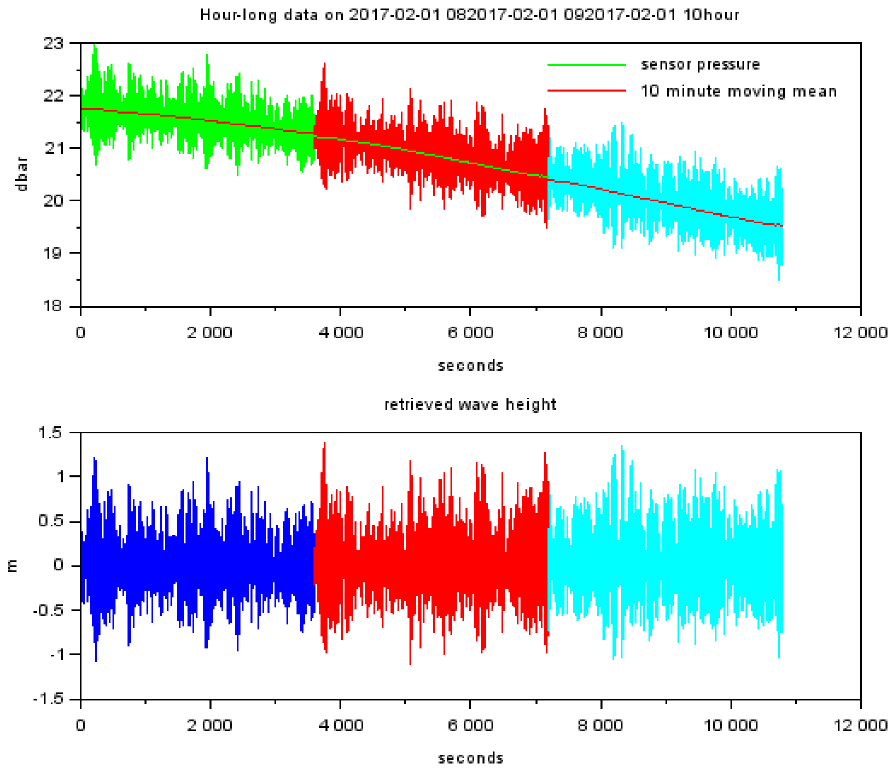

FIGURE 4 MOVING AVERAGE AND HEIGHT CALCULATION WHEN TIDE IS GOING DOWN [1]

3. CONVERSION TO WAVE HEIGHT (RHO*G)

To transform the pressure to wave height there is an equation that links these two variables with density and gravity acceleration: [3]

$$\boldsymbol{P(Pa) = \rho\left(\frac{kg}{m^3}\right) * g\left(\frac{m}{s^2}\right) * h(m)}$$

EQUATION 1 PRESSURE EQUATION

P = Pressure, the data is in dbar and for the calculation the atmospheric pressure (10.13 dbar) must be deleted from pressure data.

ρ = Sea water density in Kg/m^3, normally is 1025 Kg/m^3.

g = Gravity acceleration in m/s^2.

h = Wave height, in this case is the unknown data.

With this equation and the computation programme it is possible to calculate the wave heights from the pressure with sufficient precision. Variations in seawater density are expected to be lower than 1% for this season in this area away from any large river discharge, and their impact can be ignored in this study.

4. SPECTRAL ANALYSIS

In this analysis, the spectrum gives the distribution in frequency of the variance of the surface elevation obtained from the pressure record. Variance in a signal is usually associated with energy and in this case, in the shallow water approximation where gravity waves are non-dispersive, the energy distribution is directly proportional to the variance distribution [4]

To draw the spectrum, it is needed the time series of surface elevation variation relative to mean level and the frequency in the sample data. In addition, the spectrum can be drawn with different degrees of freedom, normally 4, 8, 16 or 32. A trade-off is typically made between reducing the range of the 95% or 99% confidence interval of the spectral estimates, which improves with more degrees of freedom, and spectral precision, which decreases with record length and thus decreases with the number of degrees of freedom used. [4]

The spectrum can be drawn logarithmically in order to appreciate better variation that in a linear-scale plot of a spectrum are not easy to appreciate. [4]

The figures 9 and 10 show the spectrum of two different days with different conditions. The first figure shows a spectrum which shows that the wave record taken during this hour had 14 second peak period. The second figure shows different sea conditions, with one peak corresponding to long period waves (roughly 20 seconds) which were probably generated in a remote storm. Other peaks at shorter periods (12, 10, 8.5 seconds and shorter) are visible, the shorter of which correspond to locally generated wind waves and the longer of which may be a mix of both.

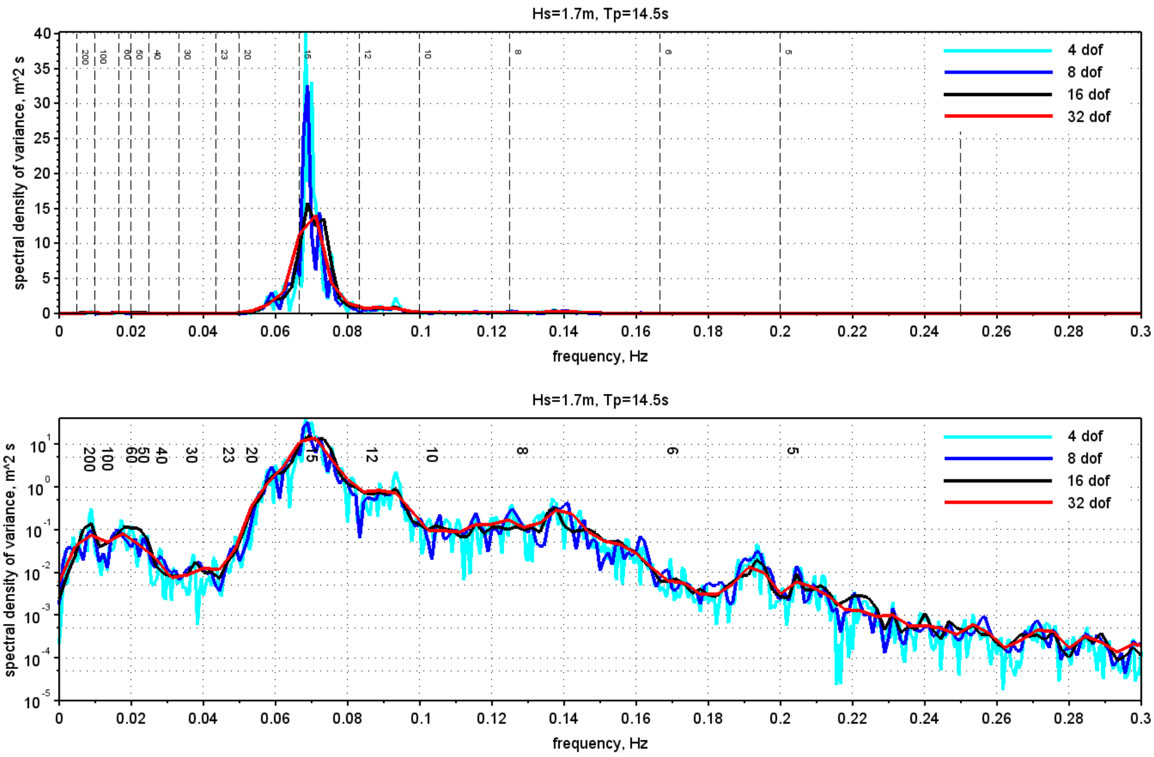

FIGURE 5 6 SPECTRAL ANALYSIS FOR THE HOUR 21 OF 2017-01-02 [1]

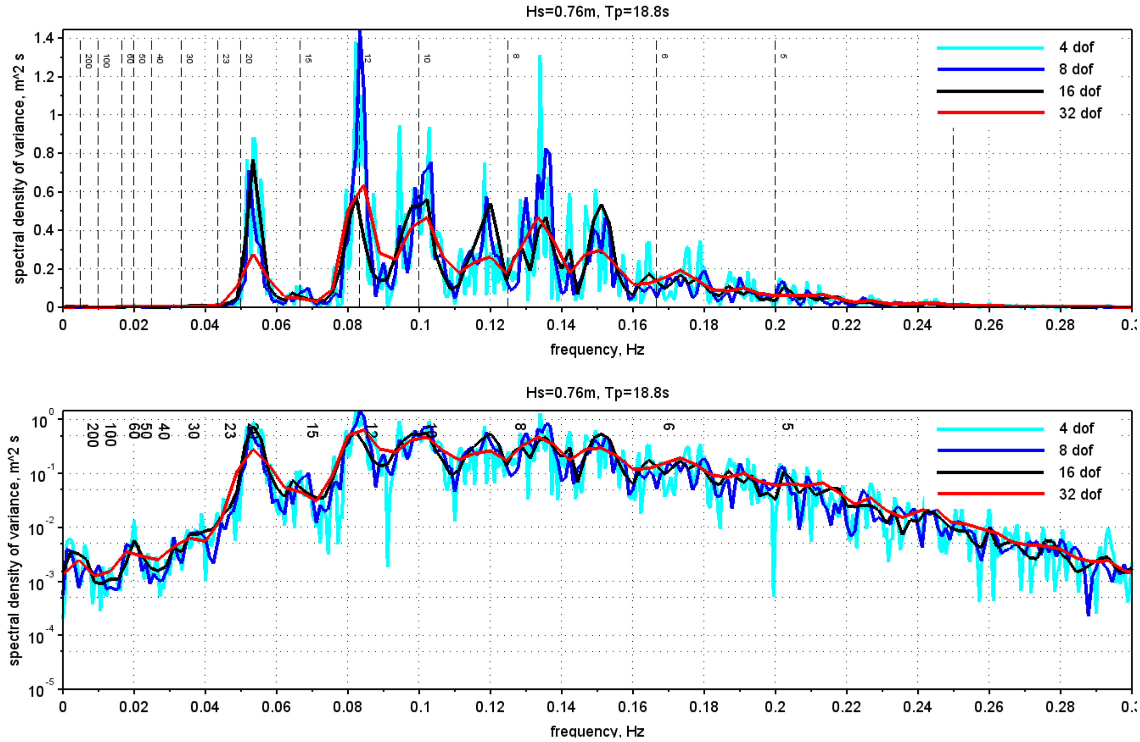

FIGURE 7 SPECTRAL ANALYSIS FOR THE HOUR 15 OF 2017-01-17 [1]

The spectral analysis gives data such as spectral significant wave height Hm_0 (m), energy mean period (s), deep water, linear Airy wave energy flux (kW/m), mean absolute wave period (s), peak period (s), $H_{1/3}$, $H_{1/10}$ and H_{max}. In this report, these values are for one hour records.

To obtain these variables the wave heights were ordered in descending order from the highest wave to the smallest with Scilab, after which the mean value of the one highest third and one tenth heights were calculated. The maximum wave height is simply the highest individual wave height observed in the hour-long record.

The first figure shows $H_{1/3}$, Hm_0 and H_{max}, during all the data collection time, and it can be appreciated that $H_{1/3}$ and Hm_0 are very similar. The second graph shows what is the variation between these two variables, in this case $H_{1/3}$ depend on Hm_0.

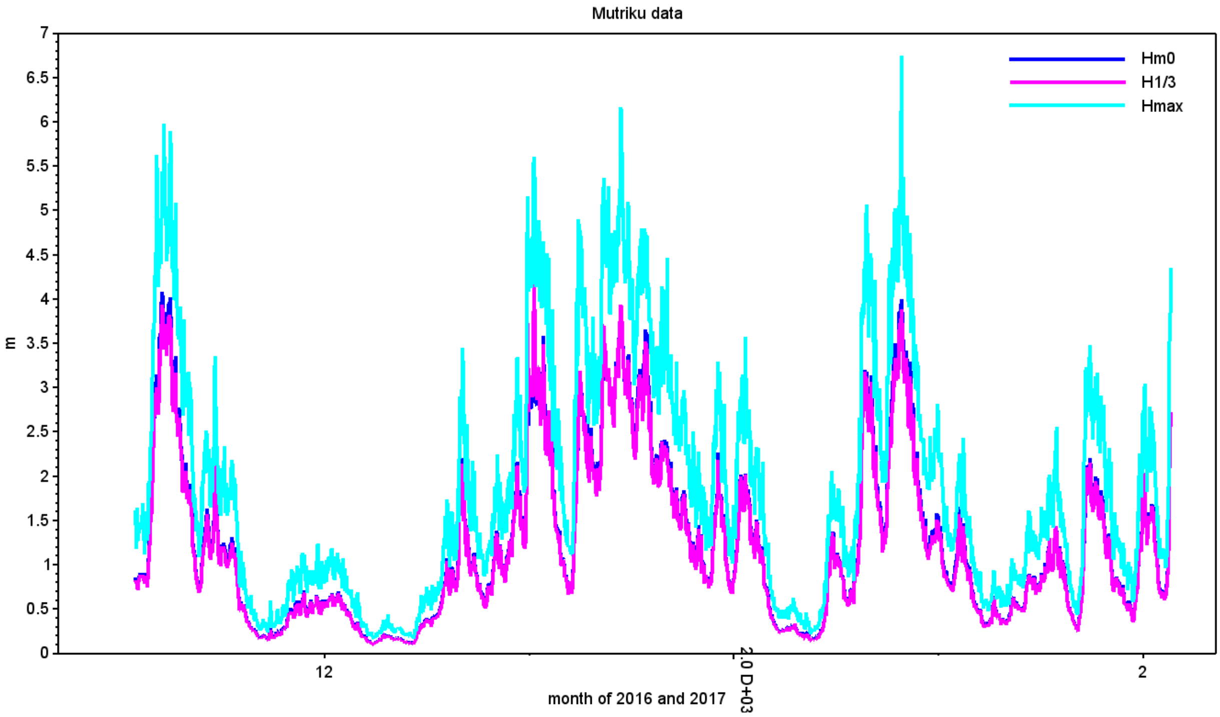

FIGURE 8 COMPARISON OF H1/3, HM0 AND HMAX DURING THE DATA COLLECTION TIME [1]

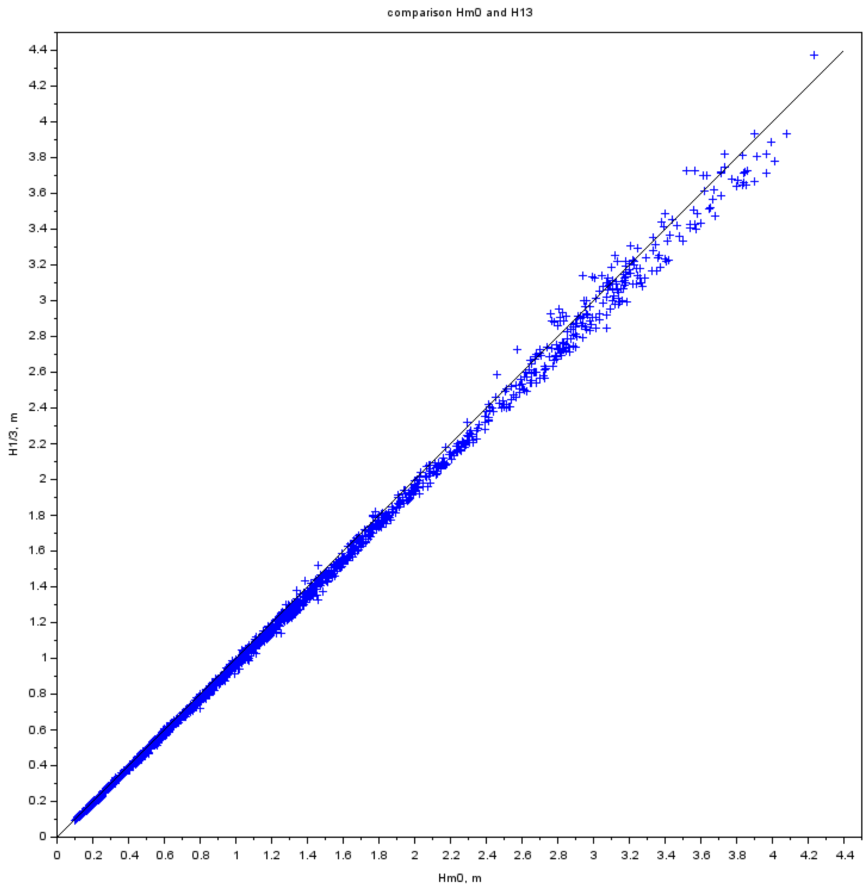

FIGURE 9 SCATTER PLOT OF H1/3 AND HM0 [1]

The next graph shows Te, Tp and Tm, during all the data collection time, and it is possible to see that, although, Tp has, usually, higher values than the other two, Te sometimes has peaks larger than 20 seconds. These values of Te should be considered with caution as discussed earlier.

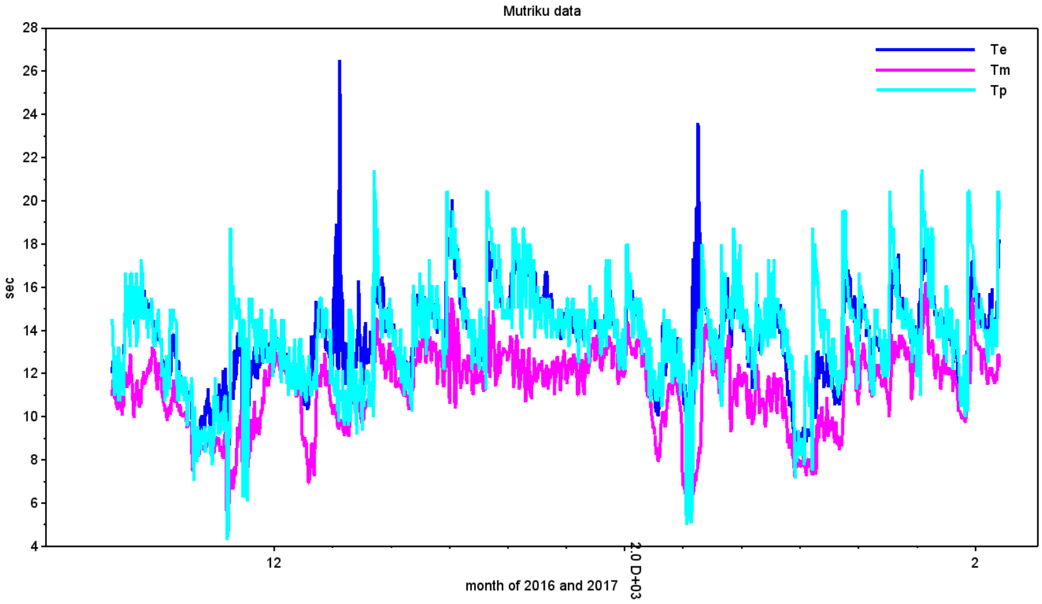

FIGURE 10 COMPARISON OF TE, TP AND TM DURING THE DATA COLLECTION TIME [1]

In the graph above two outlying peaks in energy mean period can be seen, with surprisingly high values. As discussed earlier these values are observed for days with extremely flat seas (Hs<30 cm). The figure below shows the scatter plot of the energy period vs. the spectral significant wave height. It can be seen that for Hm0<30 cm, values of Te show very high dispersion (extremely long or extremely short energy mean periods). It is suggested to ignore these data points as days with such calm seas are typically irrelevant in wave energy applications.

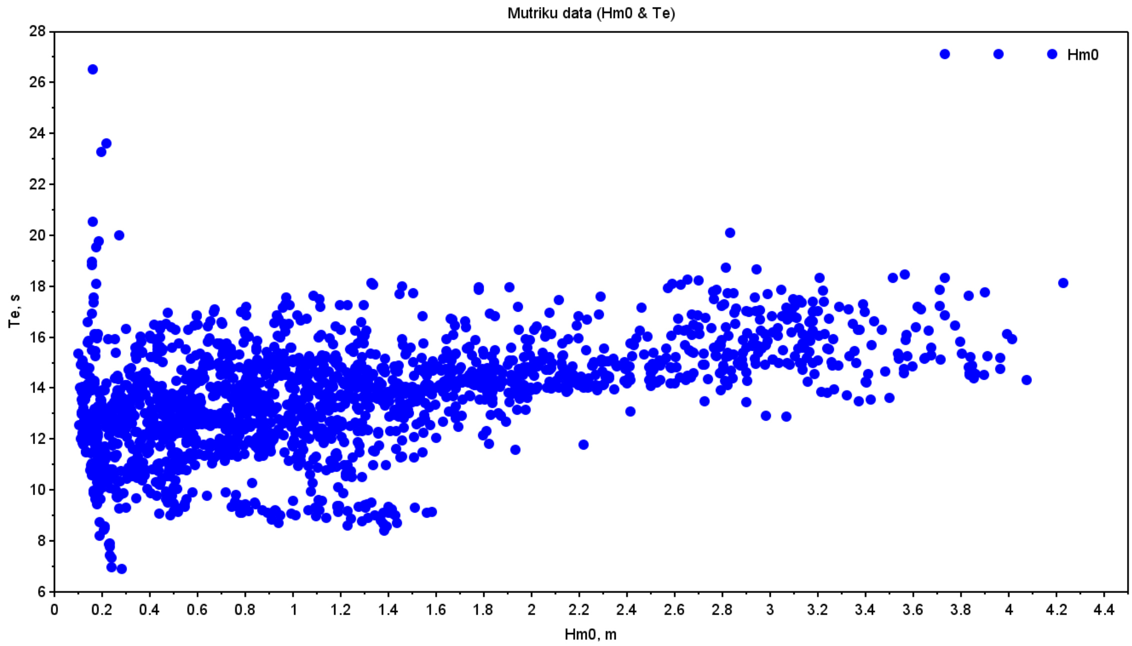

FIGURE 11 SCATTER PLOT OF HM0 AND TE TO SEE UNRELIABLE VALUES [1]

5. SEA STATES VARIABLES

In wave energy application, a sea-state is usually defined by a significant wave height (usually the spectral significant wave height) and an energy period or peak period.

5.1 SPECTRAL SIGNIFICANT WAVE HEIGHT (HM0)

The area under a spectrum is the Zeroth Moment (m_0) of a spectral distribution, in this case the distribution in frequency of the variance in surface elevation obtained from the pressure measurements. [4]

Spectrum variance has different frequency moments (m_n). The moments of the spectrum from n =-1 and n=0 shall be calculated from:

$$m_n = \sum_{i=1}^{N} S_i f_i^n \Delta f_i$$

EQUATION 2 FREQUENCY MOMENTS

In spectral analysis the significant wave height is usually noted Hm_0 and it is defined as four times the square root of m_0. [4]

$$Hm_0 = 4 * \sqrt{m_0} \qquad [4]$$

EQUATION 3 SPECTRAL SIGNIFICANT WAVE HEIGHT

The significant wave height can be defined as the average height of the highest 1/3 of the waves in a record, in which it may be noted $H_{1/3}$.

The spectral significant wave height Hm_0 and the significant wave height $H_{1/3}$ are very similar for most wave records and this was the case with the data obtained at Mutriku, as the graph below shows.

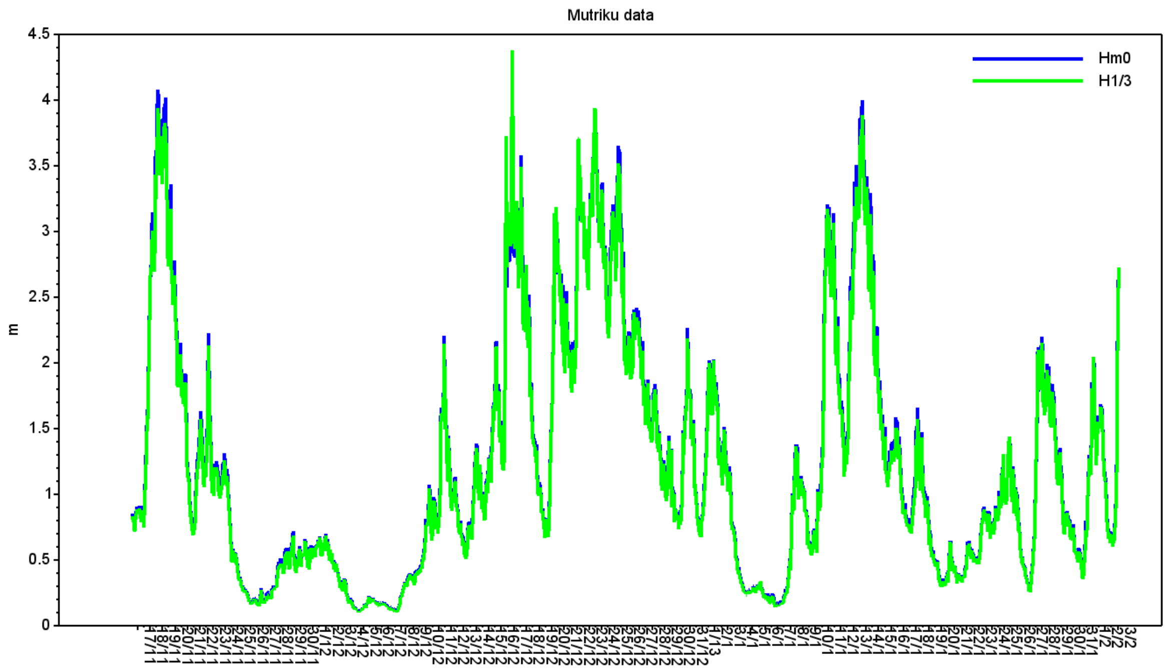

FIGURE 12 HM0 AND H1/3 DIFFERENCE [1]

5.2 ENERGY MEAN PERIOD (TE)

The energy period comes from the division of m_1, moment -1 of the spectral distribution of the variance in surface elevation, and m_0, 0th moment of the distribution .

$$T_e = \frac{m_1}{m_0} \quad [8]$$

EQUATION 4 ENERGY MEAN PERIOD

5.3 DEEP WATER, LINEAR AIRY WAVE ENERGY FLUX

The wave energy flux in the linear Airy wave in infinitely deep water can be expressed: [5]

$$J\left(\frac{kW}{m}\right) = \frac{\rho\left(\frac{Kg}{m^3}\right) * g^2\left(\frac{m}{s^2}\right) * Hm0^2(m) * Te(s)}{(64 * \pi) * 1000} \quad [5]$$

EQUATION 5 DEEP WATER, LINEAR AIRY WAVE ENERGY FLUX

Although this approximation is not valid at the point of measurement or near the Mutriku plant, this value is still provided in the time series as it is a commonly used parameter in wave energy studies.

5.4 MEAN ABSOLUTE WAVE PERIOD (TM)

In the data provided, the mean period is the mean of all zero upcrossing periods of all the waves in an hour record.

5.5 PEAK PERIOD (TP)

The peak period is taken as the inverse of the frequency with the highest value of the spectral density of variance of surface elevation, as can be obtained from our spectral analysis. [6]

The figure below shows Te, Tp and Tm obtained from the spectra during the data collection time. As expected in this location where long-period swell typically dominates short-period wind waves, the peak period is usually longer than the energy-mean period. The two instances of very high energy-mean period or obtained on days where spectral significant wave height is below 30 cm and should not be considered with caution. It is not clear our spectral analysis is valid for such calm seas, and the wave signal being so weak, it may be contaminated by other phenomena such as ship wake, atmospheric phenomena, harbour seiche, reflection off the seawall… In any case as days with such low waves are irrelevant to wave power production, these instances are not looked at in further detail, as Figure 11 Scatter plot of hm0 and te to see unreliable values [1]Figure 11 and accompanying text further discusses this point.

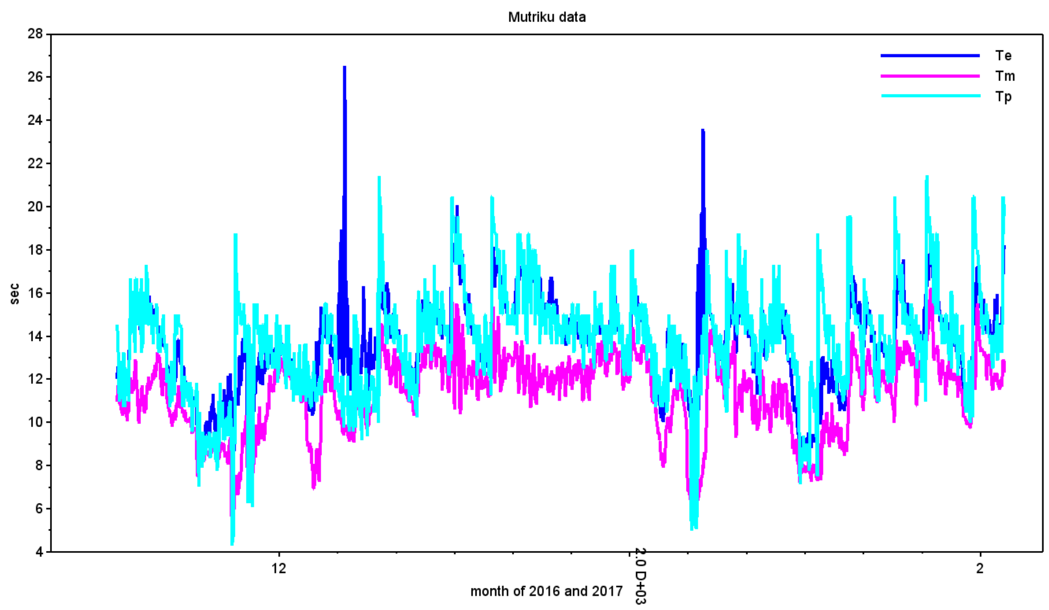

FIGURE 13 TE, TP AN TM [1]

5.6 $H_{1/3}$ - FROM 1-HOUR RECORD

The $H_{1/3}$ is considered as the significant wave height. The waves are ordered in descending height order from the highest wave until the one third of the total number of waves in the sample [7]. $H^{1/3}$ is defined as the mean value of wave height for this this highest third of the waves.

5.7 $H_{1/10}$ - FROM 1-HOUR RECORD

In this case, as with the $H_{1/3}$, the waves are ordered in descending height order from the highest wave until the one tenth of the total number of waves in the sample. [7]

This graph shows wave heights and $H_{1/3}$ (blue) and $H_{1/10}$ (red) limits:

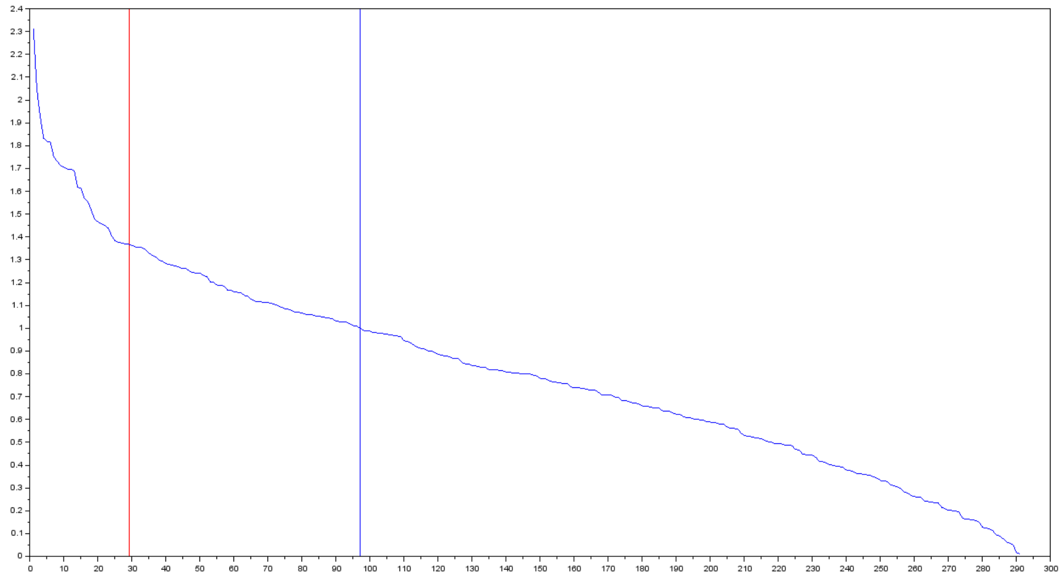

FIGURE 14 H1/3 (BLUE) AND H1/10 (RED) LIMITS IN SORTED WAVE HEIGHTS GRAPH IN 2017-01-17 15H [1]

5.8 HIGHEST INDIVIDUAL WAVE HEIGHT IN 1-HOUR RECORD (HMAX)

Hmax is the highest individual wave in the record. The Hmax values were calculated for one hour records in Mutriku from 2016-11-16 to 2017-02-03 as it is explained in the 10 minute moving average section. The graph below shows the time series of Hmax during this period, and the highest wave height recorded in all the record is 6.75 m and was observed on [2017-01-13 17h].

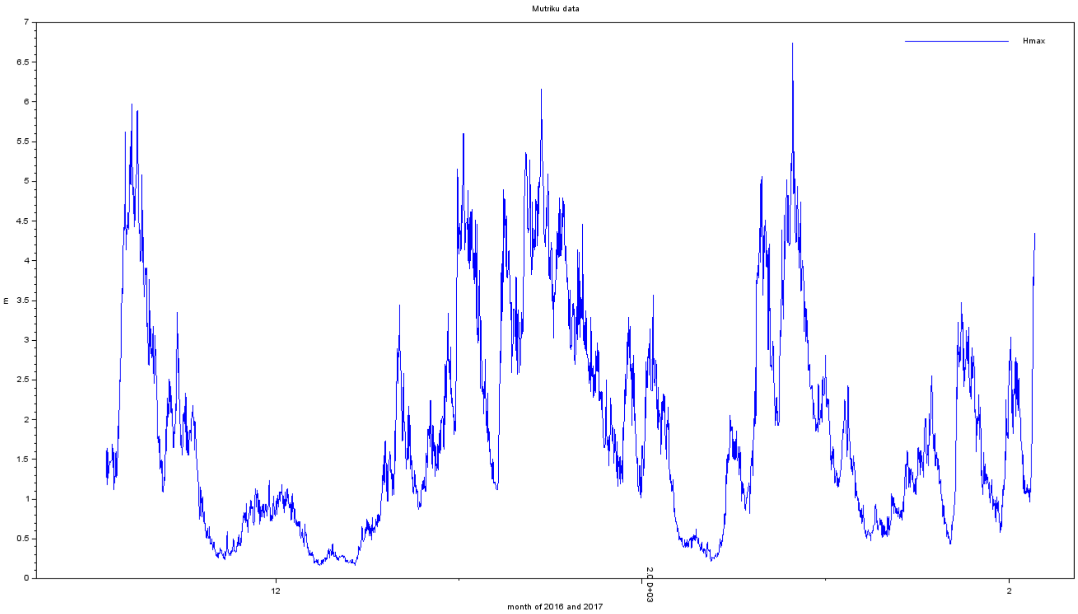

FIGURE 15 WAVE HEIGHTS DURING THE DATA COLLECTION TIME [1]

6. VALIDATION WITH NEARBY BUOY MEASUREMENTS

To verify the reliability of the data collected the full period plot was compared with the data from BiMPEP test site in Armintza.

The first graph below compares the spectral significant heights in both sites. Strong correlation can be noted, as expected from the proximity of these two locations.

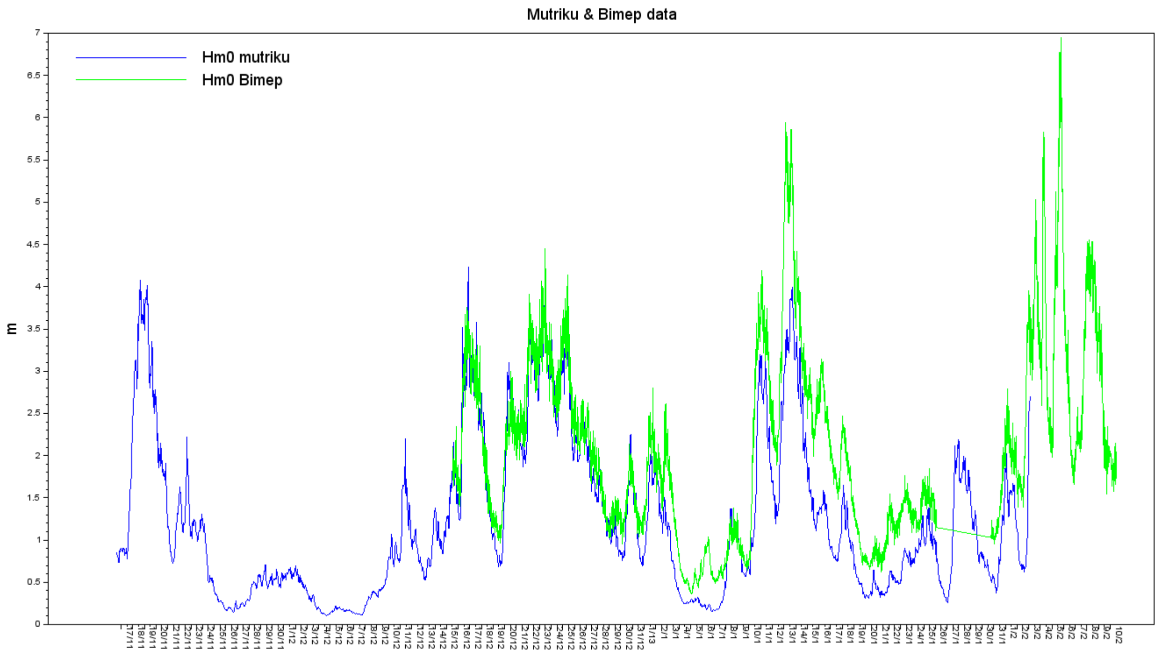

FIGURE 16 COMPARISON OF HM0 IN MUTRIKU AND BIMEP

Hm0 is usually higher in the BiMPEP Triaxys buoy data than in the pressure sensor data at Mutriku, as expected from the depth difference (some 90 m depth for the Triaxys, vs. a mean depth of 8 m for the pressure sensor).

Of potential concern is what may be a tendency for the difference to become larger in the latter half the Mutriku record. This may indicate a drift in the instrument's sensitivity. At this point this risk seems low, but should be kept in mind when using this data. Starting summer 2017, several pressure sensors will be deployed near the Mutriku plant so any potential issue with an instrument can be easily investigated.

The times series of the energy mean period from the Triaxys buoy in BiMPEP and the pressure sensor in Mutriku are plotted below. As expected, Te is consistently shorter in Mutriku, likely due to the faster attenuation of the long-period swell as it interacts with the shoaling bottom earlier than short wind waves.

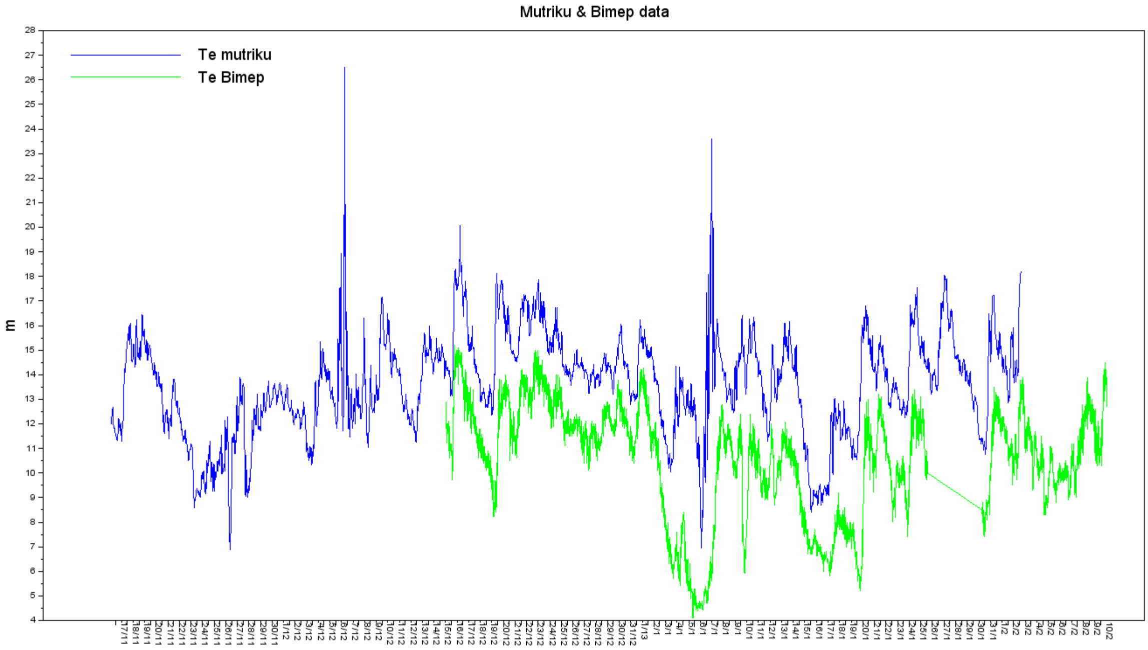

FIGURE 17 COMPARISON OF TE IN MUTRIKU AND BIMEP

7. REFERENCES

1. Enterprises, S., *Scilab*. 2008: http://www.scilab.org/. p. Scilab is free and open source software for numerical computation providing a powerful computing environment for engineering and scientific applications.
2. Wikipedia. *Moving average*. [cited 2017 19/06/2017]; Available from: https://en.wikipedia.org/wiki/Moving_average.
3. tutorvista.com. *Pressure formula*. 2017 [cited 2017 19/06/2017]; Available from: http://formulas.tutorvista.com/physics/pressure-formula.html.
4. Techet, P.A.H. *Design Principles for Ocean Vehicles*. 2005. Available from: http://web.mit.edu/13.42/www/handouts/reading-wavespectra.pdf
5. Florida, U.o. *Airy Wave Theory*. Available from: http://users.clas.ufl.edu/adamsp/Outgoing/GLY4734_Spring2014/S10_AiryWaveTheory.pptx.pdf
6. Wiki, C. *Statistical description of wave parameters*. 2007 [cited 2017 19/06/2017]; Available from: http://www.coastalwiki.org/wiki/Statistical_description_of_wave_parameters.
7. Ainsworth, T. *'Significant Wave Height' A closer look at wave forecasts*. Available from: http://www.mxak.org/weather/pdfs/waves.pdf
8. Goda, Y., *Random seas and design of maritime structures*. 2nd edition ed, ed. P.L.-F. Liu. Vol. 15. 2000, World Scientific.